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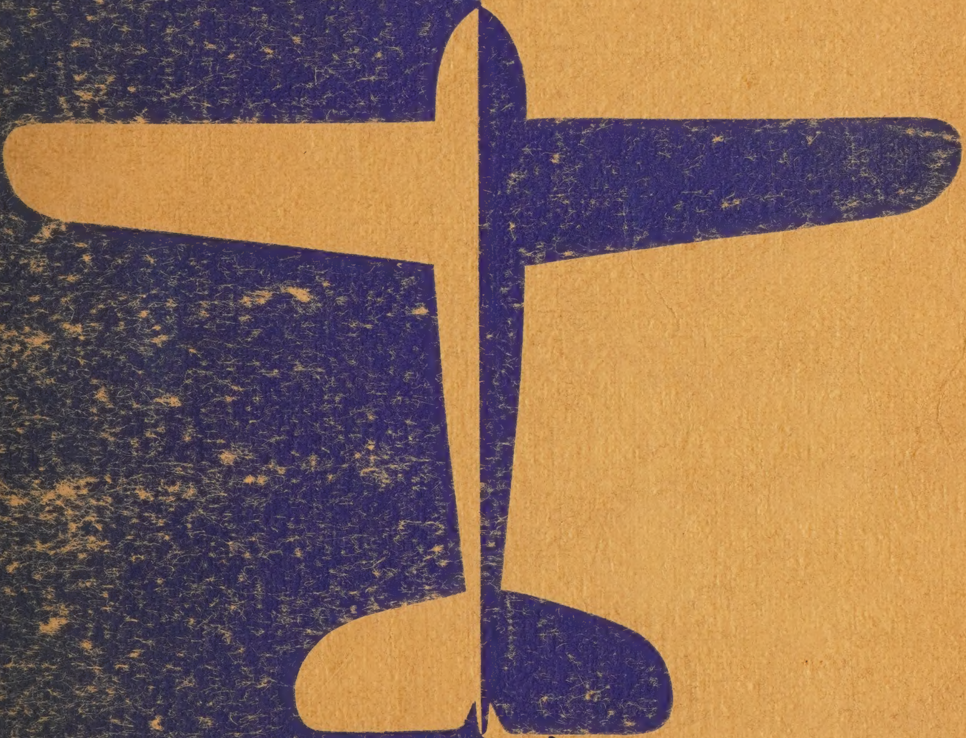
# AIRCRAFT RADIO DEVELOPMENT



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BELL SYSTEM

THIS REPRINT *of a series of articles which appeared in Bell Laboratories Record is issued to present a connected story of the development of the Western Electric aircraft radio equipment. The first article, originally printed in April, 1929, gives a general survey of the subject. The remaining articles, which appeared in October, 1930, describe the development of aircraft radio in more detail.*

# Laying A Foundation for Aircraft Communication

AIR transportation requires for its fullest success a reliable and rapid means of communication with ground stations. The experience of air transport operators during the recent rapid expansion of the aviation industry has served to emphasize the necessity of such radio communication. With a deep appreciation of this need and a full realization of the difficulties of the task, Bell Telephone Laboratories has undertaken to develop equipment suitable for this service.

The first step in the development program was taken nearly two years ago when a thorough survey was made of the communication requirements of air transport. This was followed by the purchase of a Fairchild cabin monoplane with which extensive studies have been made under actual flying conditions. By the use of this plane, a better understanding has been obtained of the requirements of such a communication system, and a quantitative study has been made of transmitting conditions encountered in airplane operation.

Such transmission studies, including radio field-strength measurements, have been made for many years in


*Fig. 1—The rod antenna and wind-driven generator may be seen in this photograph of the Laboratories' plane*

connection with the engineering of broadcasting stations and of the transatlantic radio telephone circuits. In this work, however, data was required only of the transmission efficiency between two points on the earth's surface. For this new undertaking a third dimension, altitude, was involved and an additional difficulty was brought in due to the rapid change in position of the plane.

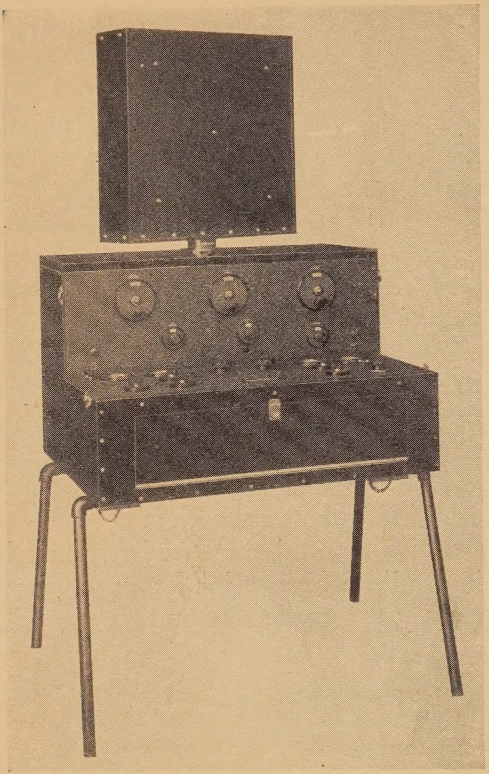


*Fig. 2—Although the 44-A Test Set is designed for use with a loop, a rod antenna was used in the tests for reasons mentioned in the text*

The first transmission measurements were made employing the Laboratories' plane, flying from Hadley Airport in New Jersey as a base. These tests were made in the frequency bands of from 285 to 315 and from 315 to 350 kilocycles which have been set aside for radio beacons and weather transmission service respectively. For measuring the signal received in the airplane, the Western Electric field-strength measuring set (44-A Test Set), of the type developed for use of the Department of Commerce, was employed. This instrument was adapted for use in the airplane by substituting a short vertical rod antenna for the loop usually employed. Similar tests were made on the Pacific coast by a field party in charge of R. S. Bair. The curve of Figure 4 is typical of the many obtained from these tests.

This particular curve is especially interesting as it shows the reduction in field strength encountered in mountainous country. From data of this kind, a determination has been made of the sensitivity necessary for an airplane radio receiver to make possible the dependable reception of beacon

*Fig. 3—E. F. Brooke operating the 44-A Test Set in the Laboratories' plane*

signals and weather broadcast transmitted by radio telephone. In general it was found that at these frequencies transmission conditions between ground and an airplane were not greatly different from those existing between two points on the ground.

It has long been appreciated that although a one-way radio telephone and beacon service may provide all the communication required for many of the smaller planes, a two-way communication system is essential to the operation of the larger transport planes, particularly when carrying passengers. It is very generally agreed among air transport operators that radio telephony should be employed rather than telegraphy for this dispatch service. The reasons for this are rather obvious. With the telephone no special training in signalling is required to allow information to be passed between dispatcher and pilot, and there is the additional advantage of having an immediate and personal assurance that the information has been received and understood. Of no less importance is the rapidity with which information may be transmitted with the telephone. It is expected that the dispatch system for the more important American air lines will develop in a manner similar to that of the railway systems, where telephony has long been widely used for dispatching.

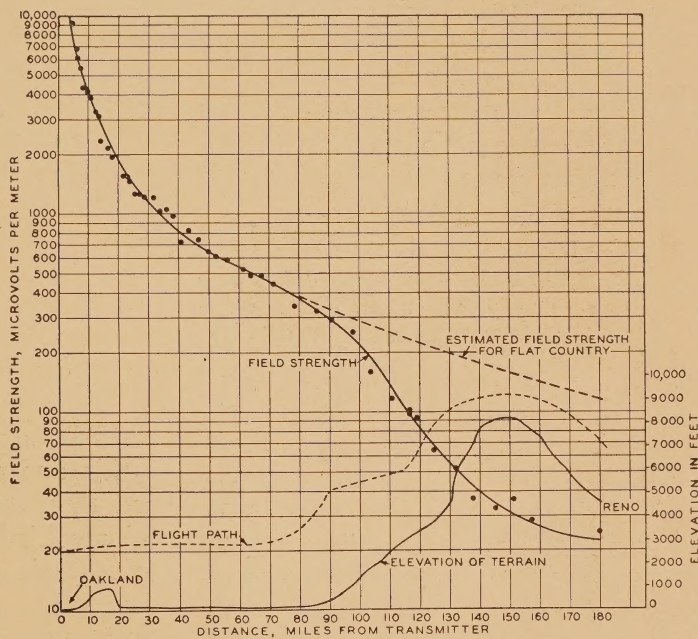



*Fig. 4—Mountains decrease the intensity of signals received in a plane as they do those at land stations*

An accurate knowledge of the transmission characteristics of that portion of the frequency spectrum available for this two-way service is the foundation upon which a system must be built. The second step in our development program consisted, therefore, in a quantitative transmission study covering the frequency range of from 1500 to 6000 kilocycles, a preliminary consideration of the problem having indicated that this frequency range afforded the greatest possibility of any that could be employed without encroaching on other important radio services. In these tests transmission measurements were made both from plane to ground and from ground to plane—employing the field-strength measuring set in both cases. The curves of Figure 5 show graphically the results of one of these tests made at a fre-

quency of approximately 1600 kilocycles. These data were taken while transmitting from Bell Telephone Laboratories' experimental station at Whippany, New Jersey, and receiving in the airplane on a flight in the general direction of Baltimore.

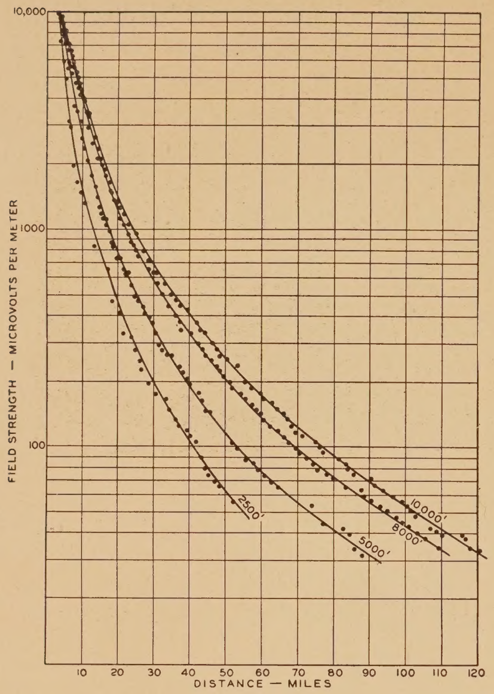



*Fig. 5—Observations made indicate a considerable increase in signal strength as the altitude of the plane is increased. The altitude for each set of readings is indicated by the figures on the curves*

These curves are typical of the large amount of data taken during flights in both the eastern and western experiments mentioned above. It will be noted that in contrast with the conditions found in the lower frequency band (285 to 350 kilocycles), the signal strength is a function of altitudes. Data taken at a frequency of approximately 5600 kilocycles at distances of from 30 to 40 miles showed the intensity of the signal to be approximately proportional to the elevation of the airplane, the signal increasing tenfold as the airplane height was increased from 1,000 to 10,000 feet. The field-strength measurements have been supplemented by quantitative intelligibility tests in which disconnected lists of words have been transmitted and a record kept of the accuracy of reception at the distant point.

The data obtained from these transmission tests have enabled the Laboratories to proceed with assurance to the design of a complete two-way radio telephone system for airplane dispatch service. The design of this apparatus has closely paralleled these transmission studies, and equipment is being designed for Western Electric manufacture which will adequately meet transmission requirements revealed by this survey. Regulatory requirements, such as that of the Federal Radio Commission decreeing that the transmitter be maintained to within .025 per cent of its assigned frequency, are also being fulfilled.


# Radio-Telephone Equipment for Airplanes

TELEPHONE communication equipment, developed by the Laboratories for airplanes, performs three functions. It permits two-way plane-to-ground and plane-to-plane communication, it enables airplane pilots to receive radio-beacon signals and weather-information broadcasts, and it allows intercommunication between as many as four points within the plant itself. Two radio receivers are required since the weather reports and navigation aids are transmitted at frequencies just below the broadcast bands, while radio telephone channels for two-way communication are assigned above the broadcast band. Further restrictions have been placed on the type and arrangement of apparatus both by Federal regulation and by the inherent requirements of airplane service. Such for instance is the requirement that two-way communication be on the same frequency in both directions, and the practical aircraft necessity that all apparatus be of minimum weight, and that its operation require a minimum of attention.

A complete radio-telephone equipment for an airplane is shown in Figure 1. The major apparatus pieces are the transmitter and the two receivers each of which, since they are remote-controlled and accessibility need be considered only for occasional repair or adjustment, may be mounted in an inaccessible place in the ship. Alike in external appearance, the two receivers differ in circuit and equipment in that one is designed to receive at frequencies in the band from 1500 to 6000 kc., and the other in the band from 250 to 500 kc. Their operation

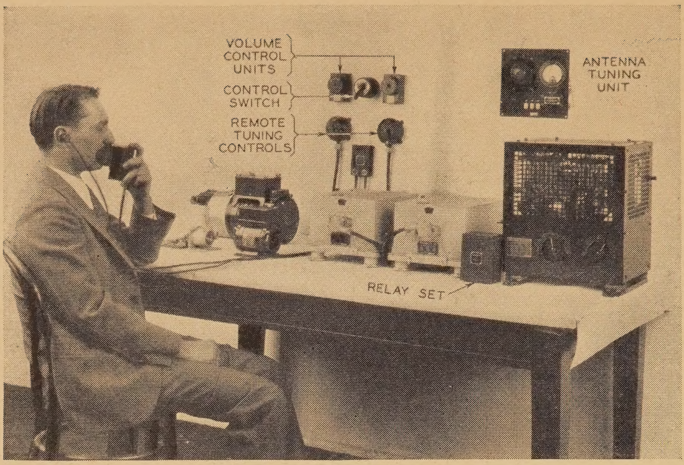



*Fig. 1—E. F. Brooke with complete radio-telephone equipment for airplanes*

and construction is described in one of the accompanying articles, and that of the transmitter in another of the articles. Besides these major items there are the antenna tuning unit, dynamotors for supplying plate and grid potentials, and several pieces of control equipment. The total weight is about 130 pounds.

Control of the equipment is centered chiefly in a small three-point switch with a position for "off", "receive", and "transmit-receive". With this switch in the receive position all head sets are connected to both radio receivers, and weather reports, navigation aids, or calls from a ground station can be received. Either radio receiver may be cut off by moving its volume control all the way to the left. The head-sets and microphones, of which there may be as many as four, are all in parallel so that inter-communication between different stations in the ship may be carried on at any time.

Because of the noise from the engines and propellers, a special silencer type of microphone has been developed for airplane use. With this device such noises are very effectively excluded and are not transmitted over the circuit to the ground station. To further improve the talking conditions, part of the microphone output is carried back to the telephone receivers, thus furnishing side tone so that the speaker can hear his own voice. Also, under these conditions the head set is disconnected from the radio receivers so that disturbing sounds may not come from the outside. The new silencer-type microphone is rectangular in shape and for talking is held close against the face with one hand.

For single-seat mail planes a somewhat lighter microphone, fastened to the aviator's helmet, as shown in Figure 4, is necessary since the aviator's hands may both be engaged with the controls. This microphone, although

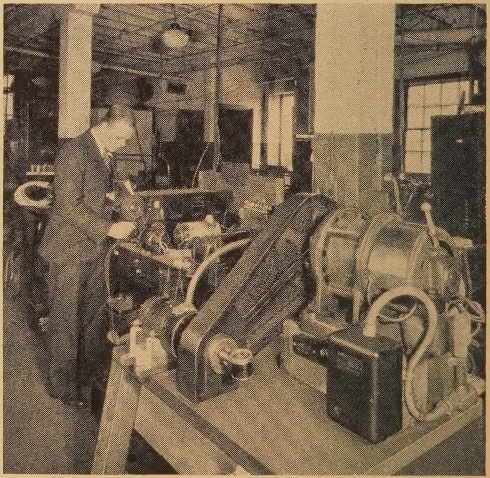


*Fig. 2—F. C. Ward conducting a test on an engine-driven generator*

*Fig. 3—The Ford tri-motored plane with fixed V and strut antennas. Standing beside it are the Laboratories pilots, Capt. A. R. Brooks and P. D. Lucas, and the ground crew: left to right, R. Zilch, C. T. Garner, and Walter Funda*

not of the silencer type, has been found very satisfactory. Used with these microphones are the small phonette receivers designed for the Western Electric audiphones, which may be seen in the first illustration.

*Fig. 4—For single seat mail planes a lighter type of microphone is used, fastened to the aviator's helmet*

Power supply for airplane telephone equipment is naturally of vital importance but there is some difference of opinion as to the form it should best take. Standard airplanes employ a 12-volt battery for miscellaneous services and so this voltage has been accepted as a basic potential for radio purposes. Unless the use of the equipment is to be rather limited, however, additional charging apparatus must be provided, and in addition higher potentials are needed for plates and grids. For these higher voltages there are three possible sources. Wind-driven generators may be employed which have the advantage of constant speed, or engine-driven generators which possess an inherently higher drive efficiency, or dynamotors may be

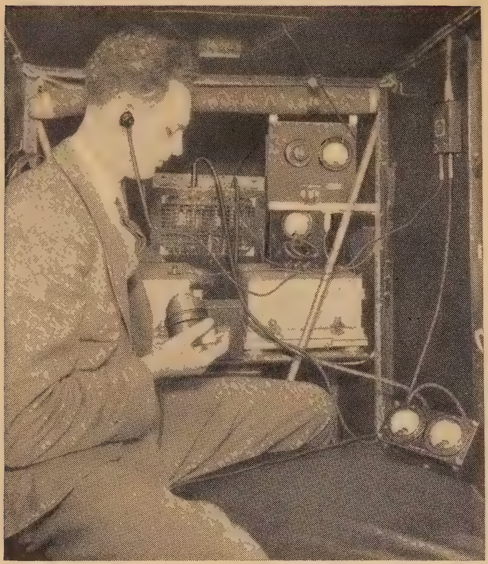


*Fig. 5—A tuning adjustment being made on the Fairchild plane by F. B. Woodworth*

utilized which are driven by the ship's batteries. The great advantage of the latter method is that power is available when the engine is stopped and even when the plane is on the ground.

There are, of course, other advantages and disadvantages to the various methods. Weights and efficiencies vary and must be given consideration. The dynamotor method allows the high-voltage supplies to be interrupted at low voltage by opening the 12-volt supply. When a dynamotor is employed, however, greater charging capacity is usually necessary which requires a larger generator. When air- or engine-driven units are used they may be made double voltage to supply both high voltage for plates and low voltage for filaments and battery charging. The testing of various possible types of generators has been no inconsiderable task and special apparatus has been set up for the purpose as shown in Figure 2.

At the present time airplane operators are allowed a choice of power supply. Generators of the three types are available and which type is selected makes little difference in the arrangement of the radio equipment.

In regard to antennas also, there is some difference in opinion, and some choice allowed. In general, the trailing wire antenna has been found most effective, but it is in some disfavor with airplane operators because of the difficulties in handling it in an emergency, and the hazard involved should the weight at the end of the wire become detached. Some form of fixed antenna is usually preferred, and the Laboratories' planes have been equipped with several experimental types as shown in Figure 3 and the headpiece.

On the Fairchild is a strut antenna with capacity loading formed by wires

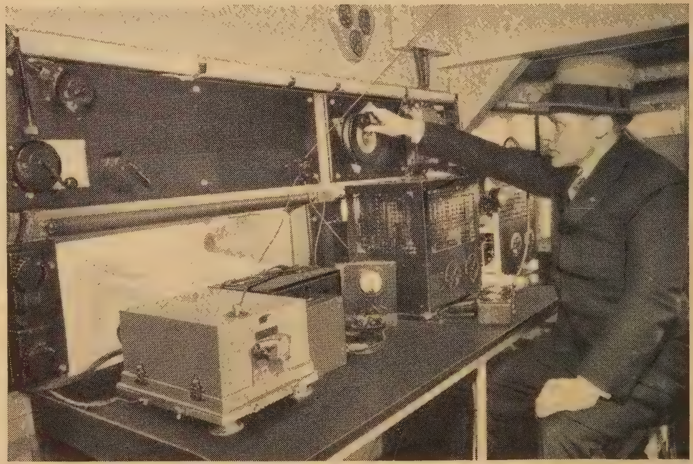


*Fig. 6—In the Ford plane is a laboratory bench for experimental apparatus. F. S. Bernhard is shown making an antenna test*

running to the wing tips and to the tail. This is used for both transmitting and receiving and gives fairly satisfactory results in the band from 3000 to 6000 kc. In the lower range from 1500 to 3000 kc. the loss due to the excessive loading required and the small effective height of such an antenna will probably bar its extensive use in practice. Boeing Air Transport, Inc., proposes to use a somewhat similar loaded strut antenna on mail planes for its Western Electric radiotelephone equipment.

The Laboratories' Ford plane has been equipped for experimental purposes with two trailing wire antennas, an unloaded strut antenna, and a horizontal V antenna—composed of wires running from the tail to struts on each wing tip—which may be used either in a V doublet or in a T connection. The unloaded strut has proven very satisfactory for receiving and is usually operated untuned because of the necessity of using it with two receivers operating at widely different frequencies. The horizontal V is more satisfactory for transmitting and will be used by Western Air Express for its radio telephone. Views of the interiors of the Laboratories' planes showing the experimental apparatus are given in Figures 5 and 6.

As has already been mentioned, the circuit arrangement will vary slightly depending on the type of power supply and antenna, but the method of

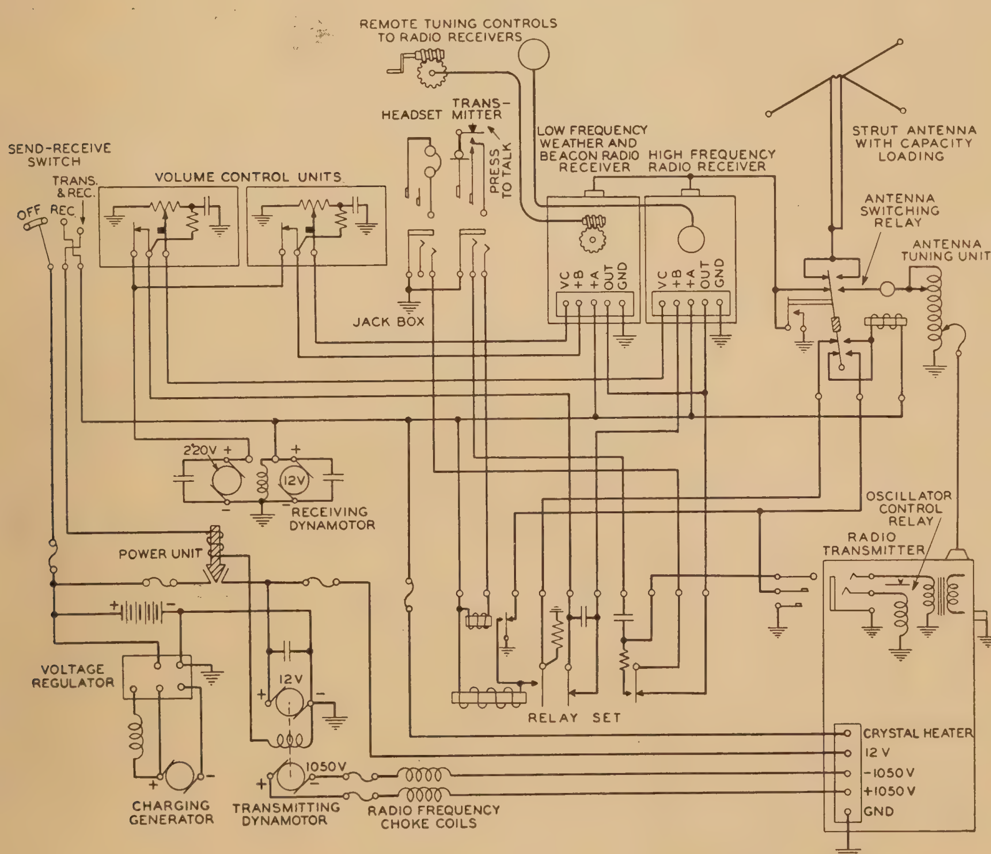



*Fig. 7—Typical arrangement of equipment and circuits for airplane use*

operation will be evident from Figure 7 showing the circuit for Boeing Air Transport, Inc.

Moving the three position control switch from "off" to "receive" puts the interphone circuit and the radio receivers into service. The single contact made in this position connects battery to both the receivers for their filaments, and to a dynamotor that supplies 220 volts for plates and grids.

*Fig. 8—W. K. Caughey listening at a ground station*

In this position signals from both receivers may be heard or interphone conversations may be carried on.

To talk on the interphone circuit a button on the microphone is depressed which makes two contacts in succession. The first supplies power to the microphone from the ship's twelve-volt battery and operates a relay set which disconnects the head-sets from the radio receivers and connects them to the interphone circuit. The second contact connects the microphones to both the interphone set and the radio transmitter but inasmuch as this is not connected to its power supply with the three-way switch in the "receive" position no speech currents are radiated.

To talk over the radio circuit the three-way switch is moved to the "transmit-receive" position. This maintains the battery connections already made and in addition connects the battery to the filaments of the radio transmitter and starts another dynamotor which supplies plate and grid potential for it. When the talk button is pressed with the contact switch in this position, voice currents from the microphone modulate the carrier current and speech is radiated. Releasing the microphone button restores the circuits to their receiving condition.

Ground station equipment, shown in Figure 8, differs from that in the airplane chiefly in the use of a larger capacity transmitter, described in another article, and in employing only one receiver. The circuit and method of operation are modified only slightly to meet this different equipment.

Many overall tests have been made of the radio-telephone service afforded by this equipment with the plane flying from Hadley Field as a base. On such trips a log is kept of the quality of transmission and other data such as distance from base, altitude, and weather conditions. Good transmission is obtained over distances up to 100 miles. Voluntary reports have been received from people who have heard the signals from distances as great as 500 miles.

# New Radio Transmitters for Airway Applications

AFTER exhaustive studies of the conditions and requirements of aviation service, two radio transmitters have been developed to serve as part of the complete airway radio equipment. One of them, known as the 8-A, is for the aircraft, and combines simplicity and reliability of operation with a degree of compactness and lightness best gauged by a glance at Figure 2. The other, for the ground station and known as the 9-A, is released from the stringent requirements of size and weight and is of greater power. The relative sizes of the two transmitters may be seen by comparing the right-hand cabinet of Figure 1 with the plane transmitter of Figure 2.

*Fig. 1—The ground-station transmitter with W. N. Mellor at the transmitter panel on the right, and J. G. Nordahl at the power control*

Both are designed to operate at frequencies from 1500 to 6000 kc, in which band the Federal Radio Com-

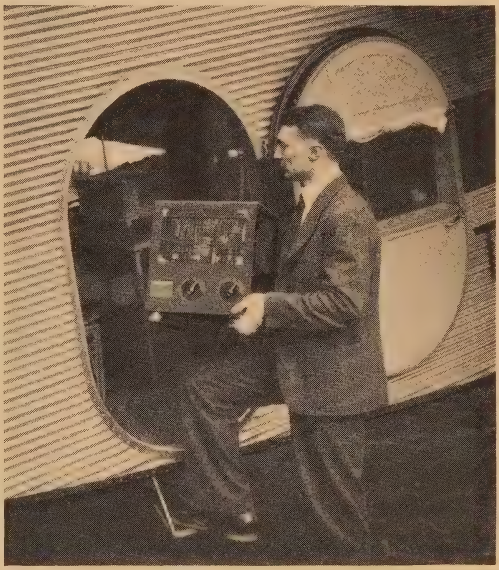


*Fig. 2—R. C. Carlton carrying an 8-A radio transmitter into the Laboratories' Ford plane*

mission is issuing licenses for airplane-to-ground communication channels. Although the range of the transmitters for satisfactory communication is given as 100 miles, they will reach much farther under favorable conditions. In addition to their projected use, these transmitters are already in

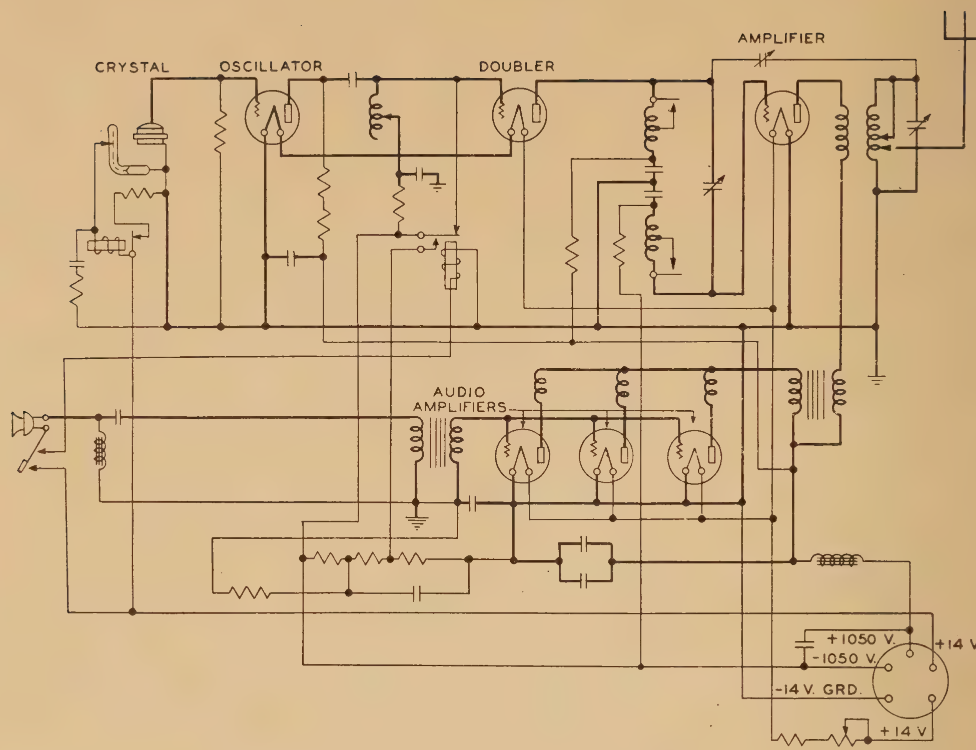



*Fig. 3—Diagram of 8-A transmitter*

demand for employment on tugs and fire boats as well as for police department work.

The 8-A transmitter, for which R. C. Carlton and H. Vaderson are principally responsible, is shown schematically in Figure 3. It consists essentially of a crystal-controlled oscillator, a frequency doubler, a modulating power-amplifier, a speech power-amplifier, and the necessary power and control circuits. Some of the principal elements may be seen in their actual location in Figure 5.

By accurate temperature control the frequency of the oscillator is held constant to better than twenty-five thousandths of 1%, even at the extreme external temperatures encountered in flying. Clamped firmly between two specially shaped metal electrodes, the crystal is maintained at a temperature of 55°C by an electric heater and a thermostat embedded in the lower electrode. These parts are heat insulated and supported by an isolantite housing arranged with connection prongs to plug into a socket similar to those used for small vacuum tubes. For the range of frequency from 1500 to 4000 kc square crystals similar to those used with broadcasting transmitters are employed. For the higher-frequency band smaller circular crystals are used. The two types of holders required to accommodate these crystals were designed by O. M. Hovgaard. Extremely small compared to those used for broadcast transmitters, their appearance may be seen from Figure 4.

The crystal frequency is only half of the radiated frequency. The output of the oscillator tube feeds into a

frequency doubler—like the oscillator a 205-D tube—which operates with a fixed bias and large grid leak to augment the generation of harmonics. A parallel-tuned circuit fed by the plate selects the second harmonic to act as input for the modulating amplifier.

The plate circuit of the modulating power-amplifier, which employs a 211-D tube, is tuned by a condenser across the secondary of a close-coupled radio-frequency transformer which has taps for connection to the antenna. To span the entire frequency range, two of these transformers are required and are readily interchanged by means of four clamping screws which also make the four necessary connections. Plate modulation is accomplished by supplying a thousand-volt direct-current

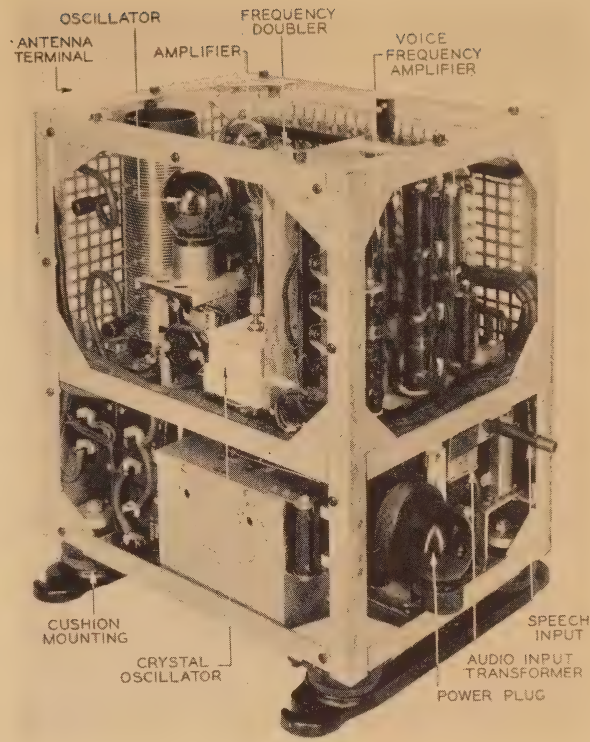



*Fig. 5—Removing the two sides and cover of the 8-A Transmitter shows the compact disposition of its component parts*

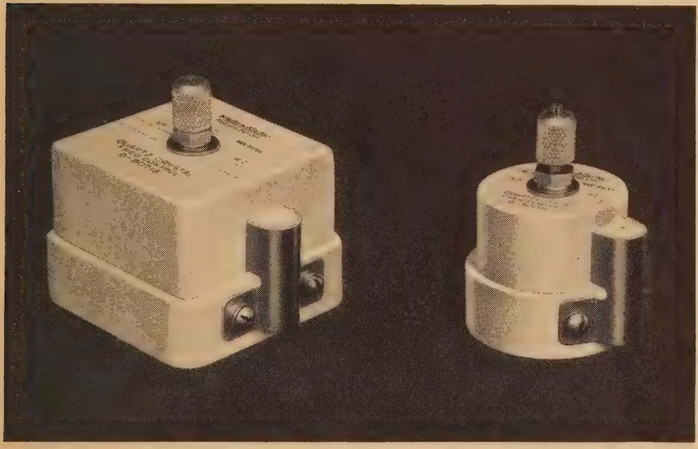


*Fig. 4—Crystal containers are small and have prongs for plugging into a socket of the vacuum tube type*

potential through the secondary of the output transformer of the audio power-amplifier. The radio-frequency transformer insulates the plate voltage from the antenna and the tuning condenser. The amplifier is neutralized by the Rice method from voltage developed bv half of the input coil.

Audio-frequency amplification is by three 211-D tubes connected in parallel, which supply sufficient power for complete modulation. Special transformers are used for input and output circuits, the former with permalloy cores. Developed by the group under E. L. Schwartz, they are light and very small, as shown in Figure 6 where one of them appears beside the

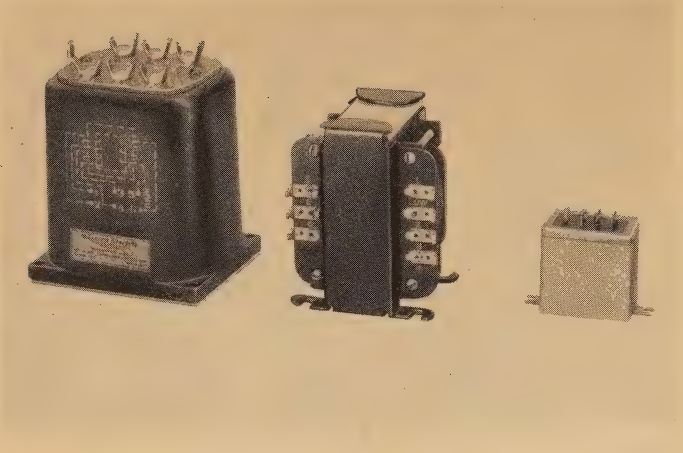


*Fig. 6—The audio-frequency transformer weighs but four ounces in remarkable contrast with the four-pound transformer used for broadcasting*

in Figure 9, which is a recent development of the vacuum tube research group. A rotating coil, inductively coupled to the output of the modulating amplifier, supplies its grid input and neutralizing voltages. The output circuit is tuned by the constant-impedance type of circuit with a variable inductance and capacitance coupling to the transmission line.

An antenna tuning unit, shown in Figure 10, is enclosed in a copper box for protection and shielding, and is arranged for wall mounting. It consists of a variometer with a tapped stator and fixed series condenser for resonating the antenna to any desired frequency. The transmission line is clipped on the proper turn of the variometer to match the

corresponding broadcast transformer.

To obtain a quiet source of power for the filaments, approximately fifteen amperes at twelve volts is taken from the ship's battery which is ordinarily floated across a charging generator. For the thousand-volt plate supply, at which about four-tenths of an ampere is needed, a separate generator may be used, or—as is sometimes desirable—a dynamotor driven from the ship's low-voltage battery. Connection of these power supplies to the transmitter is made through a single plug shown in the illustrations.

The ground transmitter, shown schematically in Figure 8, is essentially the same as the 8-A but includes a power amplifier in addition to increase the power of the modulated carrier. Its carrier output, also capable of complete modulation, is 400 watts—eight times as great as that of the 8-A. The power amplifier uses a 251-A vacuum tube, shown

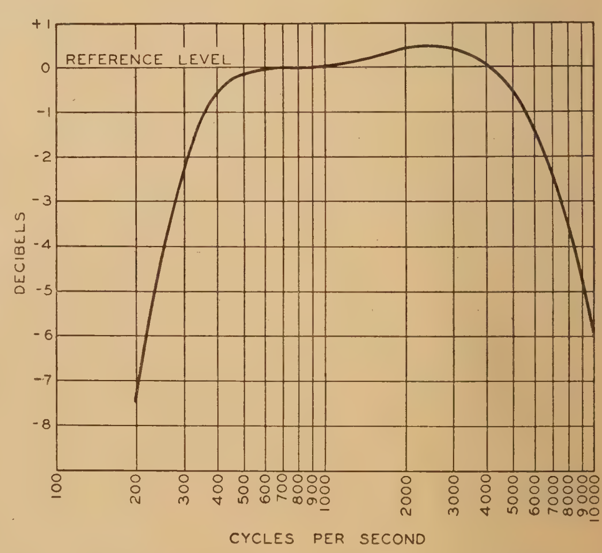



*Fig. 7—Overall audio-frequency characteristic of the 8-A transmitter*

impedance of the line. This arrangement is sufficiently flexible to work with antennas of widely different resistance and impedance characteristics and is simple to adjust.

Power for the ground station is supplied by a rectifier, shown beside the transmitter in Figures 1 and 9, which was developed by J. G. Nordahl and H. Vaderson. It is known as the 2-A and supplies all power for filaments, grids, and plates. The set is push-button operated, and safety switches are provided on all cabinet doors which disconnect the power supply when the doors are opened. A total of about three kilowatts of sixty-cycle, three-phase, 220-volt power is required for the operation of the transmitting equipment at the ground station.

*Fig. 9—Rear view of the ground transmitter and power cabinets. A 251-A tube is being inserted by J. B. Bishop*

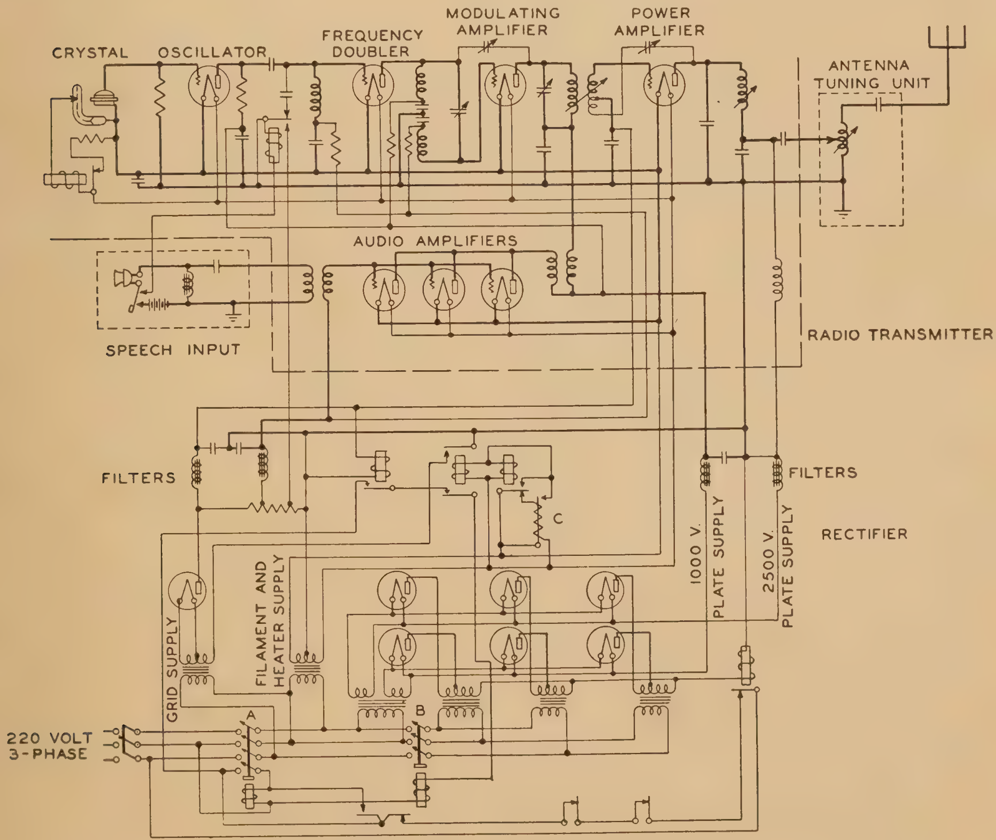



*Fig. 8—Diagram of 9-A transmitter*

All filaments, and the heater for the crystal oscillator, are supplied from a transformer with a grounded center tap.

Plate power, at two voltages, is obtained from two three-phase mercury-vapor rectifiers — one supplying plate voltage for the power amplifier, and the other supplying a lower voltage for all other tubes. One set of three

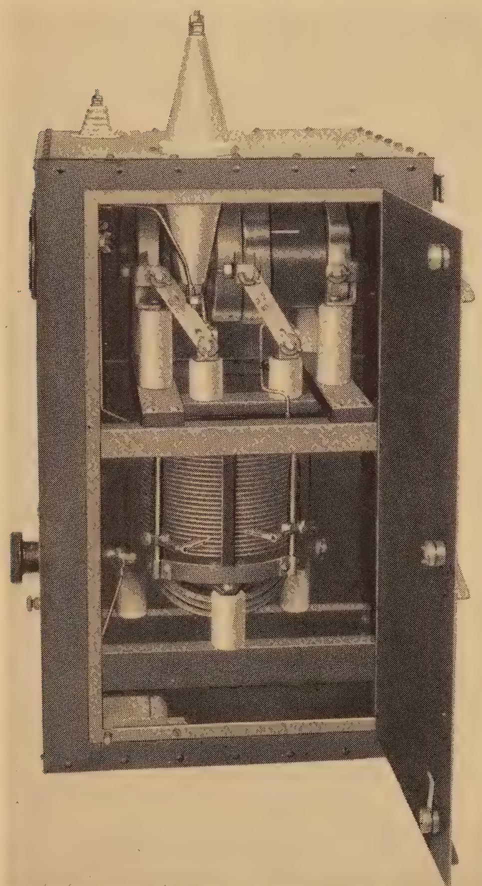


*Fig.* 10 — *The antenna coupling unit, copper enclosed, mounts on the wall in any convenient location*

transformers serves both rectifiers but the secondaries are tapped for the lower-voltage rectified. The rectifier filament circuits are specially insulated, and operated at the plate voltage above ground in both rectifiers, which allows the center of the star-connected transformers to be grounded through an overload relay for protection. Single section filters are provided in each plate supply to reduce the low-frequency ripples to less than 1% of the DC voltages.

One tube is used in a single-phase half-wave rectifier for grid-bias voltages. This rectifier works directly into a load resistance, and the two voltages desired are obtained from taps on that resistance. Single section filters are used here also for each voltage.

The set is put in service by pressing the start button as J. G. Nordahl is shown doing in Figure 1. This operates switch A of Figure 8, which holds itself in through a series circuit including the various door switches and the overload relay. The closing of this switch energizes all filament circuits in both transmitter and rectifier. The filament voltage, after an interval of about 10 seconds, operates a thermal relay, C in the illustration, which in turn actuates a relay to put plate voltage on the grid-bias rectifier. As the grid-bias voltage builds up another relay, B, is operated which puts plate voltage on the two high-voltage rectifiers and the set is in operation.

The overall audio-frequency characteristic of the 8-A transmitter is shown in Figure 7. The characteristic for the 9-A is substantially the same as that for the 8-A.

A very considerable number of both of these transmitters are already in successful operation on the airways of the United States and are proving very satisfactory.

# Aircraft Radio Receivers

IN the design of radio receivers for airplanes, besides such special requirements as are necessitated by the unusual conditions encountered, the good old-fashioned requirement of reliability assumes increased significance. After coming to depend upon the many advantages afforded by the successful reception of weather reports and beacon signals, for example, a pilot is likely to find himself in serious trouble if the radio equipment should fail at a critical moment. Unfavorable weather conditions at his destination, of which he could be advised by radio, might make a change in his plans desirable, or, if he had risen above the clouds to avoid bad weather—depending on the radio beacon to guide him—its sudden failure might result in his becoming completely lost and being forced down in unfavorable terrain through exhaustion of his fuel supply.

The Western Electric 9-A and 9-B radio receivers have been developed to meet certain specific needs of the aircraft industry for reliable radiotelephone communication. In their mechanical design, for which B. O. Browne was largely responsible, they are as nearly alike as possible, thus effecting a considerable economy in the cost of manufacture through the use of identical parts for the more important structural units. The receivers are clamped to a special mounting which provides some degree of cushioning against the shocks and vibration encountered in an airplane. Although every effort has been made to reduce the weight, no sacrifice of strength or rigidity that would impair the performance or reliability has been permitted. This has resulted in a well balanced mechanical design which has proved very satisfactory and will provide a firm foundation for further

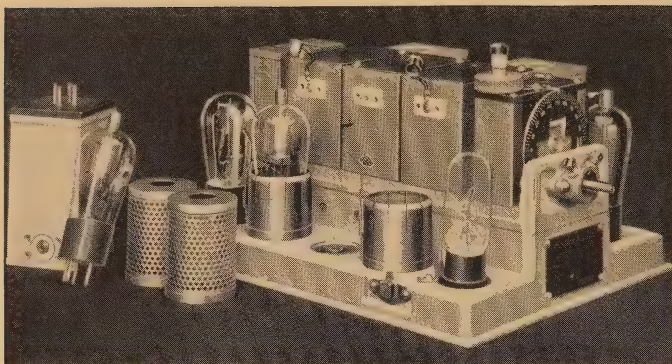


*Fig. 1—Major elements of the radio receiver are arranged in three rows with tuning condensers down the center and plug-in coils and tubes on the two sides*

refinement and for the development of other similar equipment.

The base casting of these receivers not only serves as a light, rigid support for all of the apparatus but, by the proper use of the partitions which act as strengthening webs, provides some of the shielding required between the various parts of the circuit which is so necessary in a high-gain receiver.

This shielding is particularly essential since the dimensions have been reduced as far as possible because of the limited space available for aircraft radio equipment. Despite the compactness of the design, however, a reasonable degree of accessibility has been maintained, and it is possible to make practically all of the soldered connections after the assembly has been completed, which is very desirable from a manufacturing standpoint. This is greatly facilitated by the use, wherever possible, of condensers with pigtail connections instead of soldering terminals, which permits mounting the condensers in inaccessible positions while the terminals to which the leads are connected are readily available.

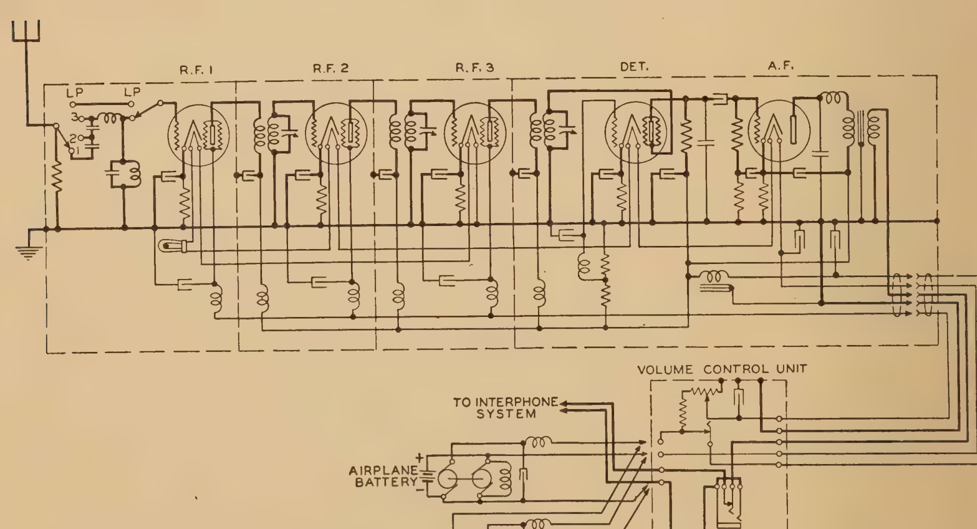



*Fig. 2—Schematic diagram of 9-A radio receiver*

A view of the receiver with the cover and some of the tubes and plug-in coils removed is shown in an accompanying illustration. The cover is held in place by four light catches similar to those used on suitcases, and only the loosening of these catches and the disconnection of the antenna lead are required for tube replacements or for changing the coils. A strip of soft felt around the entire receiver, together with a sponge-rubber washer around the antenna binding post at the top of the set, renders it substantially dust proof when in service.

A three-gang tuning condenser is mounted in the center of the set and the shaft terminates at one end in a dial visible through a window in the cover. A worm-gear drive with a flexible shaft and a remote control unit permits tuning the receiver from any distance up to forty feet. The drive may be turned to any position to facilitate the installation. A gear ratio of 264 to 1 between the flexible shaft and the condensers reduces lost motion to a negligible amount. For ground-station operation the flexible drive may be replaced by a knob for local control, which is designed to cover up the clamping arrangement for the drive, and the ratio of six to one between it and the condenser shaft gives a very satisfactory tuning adjustment.

On one side of each condenser shield is mounted a lead for the grid of a vacuum tube, and on the other side, a pin which engages a jack on the shield of a plug-in coil. These pins also serve to hold the coils in place. Each coil is completely shielded and the other connections to it are made through the socket into which it plugs. Two of the tubes are shielded by perforated cylinders which hold the tubes in their sockets, and in turn are themselves held in place by special spring clips.

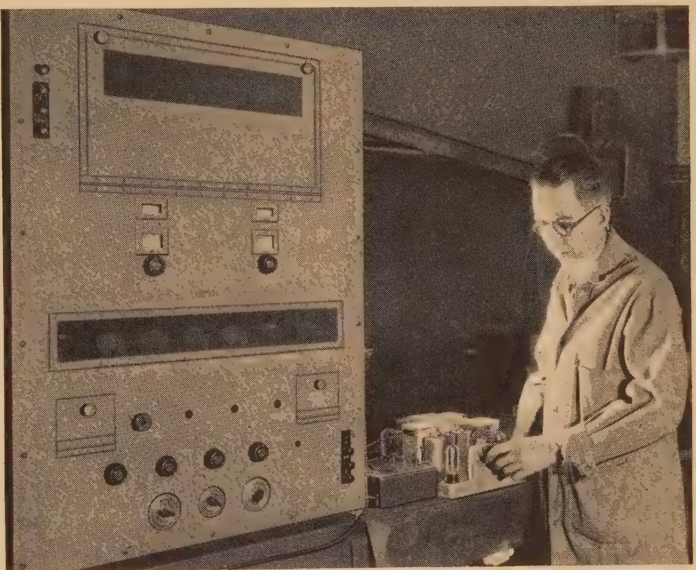


*Fig. 3—H. B. Fischer testing a 9-A radio receiver in the shielded room*

The tubes that need no shielding are secured by springs which engage a pin on the tube base, while the ballast lamp is held in place by a toothed spring engaging the ridge near the lower end of the base. Any possibility of a tube or coil working out of its socket due to vibration is thus eliminated. The alternate arrangement of the tubes and coils on the two sides of the tuning condensers results in the shortest possible grid and plate leads.

At the rear end of the set is a multiple point receptacle for making all necessary electrical connections except

*Fig. 4—W. E. Reichle talking to P. D. Lucas and adjusting the volume control of the 9-A receiver in the Laboratories' Fairchild plane*

that to the antenna. The plug that fits this receptacle is supplied with a special collar which shields it and locks it firmly in place. Shielded cables connect the receiver to other units of the radio installation.

A schematic circuit of the 9-A radio receiver, for the development of which H. B. Fischer and W. E. Reichle have been directly responsible, is shown in an accompanying illustration. This receiver is designed primarily for the reception of the weather reports and radio beacon signals transmitted by the United States Department of Commerce. It covers the frequency band from 250 to 500 kilocycles and has a sensitivity limited only by the tube and circuit noises. A signal input of 5 microvolts with average telephone modulation is more than sufficient to give an output of six milliwatts. For headphone reception, as used in airplanes, this gives a signal sufficient to override noise from the engine and propeller. Reserve power is available to supply several sets of headphones if desired.

The receiver employs three stages of tuned radio-frequency amplification using 245-A vacuum tubes, a space charge grid detector using the same tube, and one stage of resistance-coupled audio-frequency amplification using a 244-A vacuum tube. The three inter-stage circuits are tuned with a single control as already mentioned and provide a high degree of selectivity.

The antenna circuit consists of a single-section band-pass filter. This eliminates interference from outside the desired band, especially that from powerful broadcast stations which is likely to be severe under some conditions. It also permits the use of the receiver on the same antenna simultaneously with a 9-B radio receiver, used for two-way radio-telephone communication, without seriously reducing the efficiency of the latter. A special connecting link, together with a movable grid connection to the first tube,

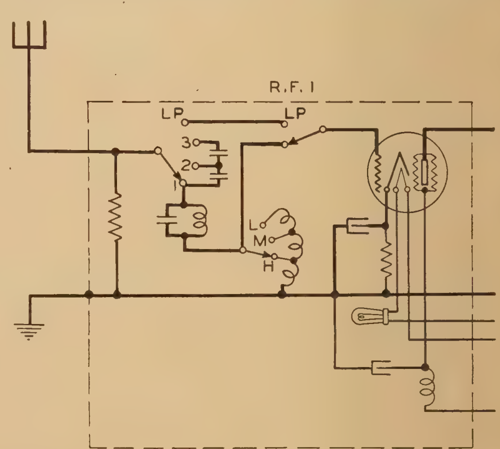



*Fig. 5—Schematic diagram of antenna tuning unit of 9-B receiver*

permits the complete elimination of this special filter when it is desired to use either a loop antenna or an external antenna-tuning unit.

Remote volume or sensitivity control is obtained by a tapered potentiometer with a filter condenser, which controls the voltage on the screen grids of the radio-frequency amplifier tubes. The change in sensitivity is approximately uniform over the entire range. Where only a radio receiver is installed, a control unit is employed which includes a jack for the headphones and a substantial switch for turning the complete equipment on or off. For complete two-way installations the switch is omitted from the control unit.

When a storage battery is available on the airplane, especially when it is equipped with a charging generator, it usually furnishes power for the receiver. The filament circuit is connected directly to the battery while plate voltage is supplied by a dynamotor which is driven by it and weighs, complete with its filter, only about eight pounds. This is less than half the weight of the lightest practicable plate battery, which would also have the disadvantage of requiring frequent replacement.

When no storage battery is available, or when a charging generator is not used so that the extra current drain of the receiver cannot be tolerated, power can be obtained from a small wind-driven generator. The propeller of this generator is of the single-blade, self-regulating type. The apparent unbalance of the single blade is fully compensated for in the regulating mechanism, which, by changing the angle of the blade, keeps the speed within very close limits for all normal flying speeds above 70 miles per hour. The generator complete with propeller weighs but seven pounds.

All of the power-supply circuits are carefully filtered and shielded from each other to avoid undesirable regenerative effects, and the shielding of the radio-frequency amplifier circuits is likewise made as complete as possible. The output circuit embodies a shielded transformer of the proper ratio to fit the interphone circuits used with the two-way system.

*Fig. 6—E. S. Dobson removing a 9-A and 9-B receiver from the Laboratories' Ford plane*

All of the vacuum tubes are of the heater or unipotential cathode type which permits the use of noisy sources of filament supply, such as a generator, without elaborate filters. Filtering is required only to eliminate the radio-frequency interference due to spark-

ing at the commutators. The heaters are all connected in series and a ballast lamp permits a variation in the supply of voltage from 11.5 to 14 volts without a serious change in the filament current from its normal value of 1.6 amperes. An adequate plate-supply filter is also incorporated in the receiver. The plate voltage required is from 200 to 220 volts, and the total current drain, including that for the shields and their associated potentiometer is from 20 to 25 milliamperes.

The circuit of the 9-B radio receiver, designed for use with two-way radio-telephone systems, is substantially identical to that of the 9-A except for the antenna circuit. Its frequency range is from 1500 to 6000 kilocycles. The many special problems arising out of the necessity for obtaining extreme sensitivity and selectivity at these high frequencies, and in a very limited space, with a single tuning control have been solved by R. H. Herrick and E. S. Dobson. Although the sensitivity is not so great, because of the higher frequencies, as that of the 9-A radio receiver, a signal input of 10 microvolts is sufficient to give the standard zero-level output of six milliwatts.

The antenna circuit for the 9-B receiver differs from that of the 9-A in employing an adjustable tap on one of the filter inductances which is changed in accordance with the particular frequency range being used. The 9-B receiver, due to the greater liability of regeneration at these higher frequencies, also requires more elaborate filtering in the detector plate circuit. The only other major differences between the two receivers are in the size of the tuning condensers and the power-supply chokes.

A demonstration set-up of a complete radio receiving outfit, including the receiver proper, its remote control units, and two alternative sources of power supply, is shown in the accompanying illustration. The weight of the complete outfit amounts to approximately forty pounds.

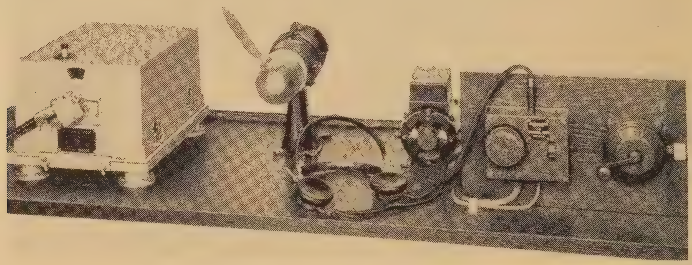
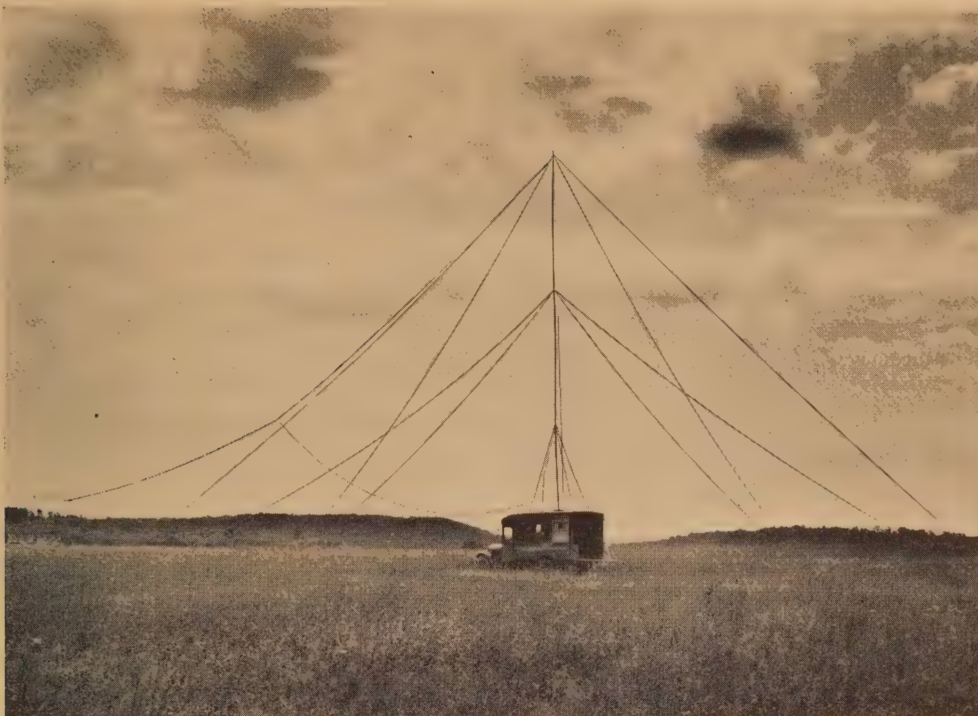


*Fig. 7—Complete low-frequency weather and beacon receiving outfit showing alternative power supplies*



# Test Truck for Aircraft Radio

RADIO - TRANSMITTING stations mounted on trucks have been frequently used by Bell Telephone Laboratories in making transmission studies and field strength surveys at both broadcast and transatlantic frequencies. A need has recently arisen for a similar portable station to operate at the frequencies employed for communication with aircraft. For this purpose the two-ton truck shown in Figure 3 has been equipped with complete 400-watt ground-station apparatus for operation from commercial three-phase power supplies. A 50-watt airplane equipment operating from a 12-volt storage battery has also been installed for use at places where commercial three-phase power is not available.

The interior of the truck is shown in Figure 2. At the left are the aircraft-type radio receivers, and, to the right of them, the aircraft transmitter with its antenna tuning unit above. Near the center of the truck are the ground station units; the 9-A radio transmitter at the left with the antenna coupling unit directly above, and the 2-A rectifier at the right. The latter, because of its greater weight, is placed as near the center of the truck as possible. In the cabinet under the aircraft equipment are spare tubes and miscellaneous equipment. The smaller cabinet near the tail board contains an amplifier for use with the public address system.

On the same side of the truck, between the spare-tube cabinet and the ground-station transmitter, are the aircraft dynamotors. One supplies 200 volts for the receivers and the other, 1,050 volts for the transmitter. Above them, mounted on the end of the cabinet and not visible in the photograph, is the necessary relay and control apparatus.

A charging generator geared to the truck's motor supplies 12 volts for charging the 400 ampere-hour storage battery mounted on the right-hand side of the truck as shown in Figure 1. Beside the battery is a reel of 200 ft. of three-conductor cable used for connecting to the nearest 220-volt 60-cycle supply for operation of the ground-station transmitter.

A tungar rectifier is available for charging the battery when 220-volt power is available. It is mounted against the front end of the truck at the left and is just visible in Figure 2.

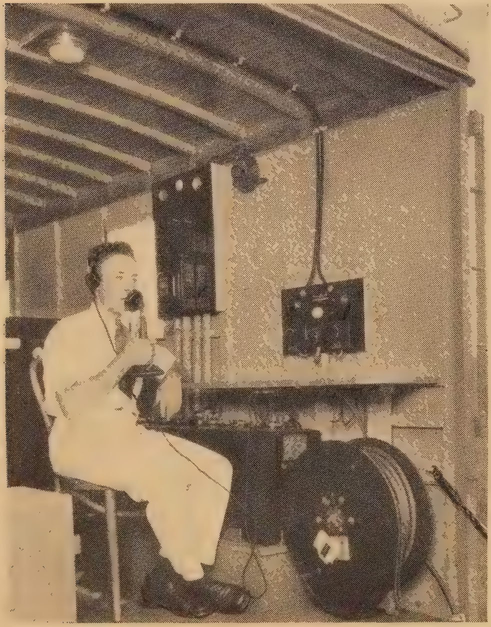


*Fig. 1—J. M. Henry in communication with an airplane*

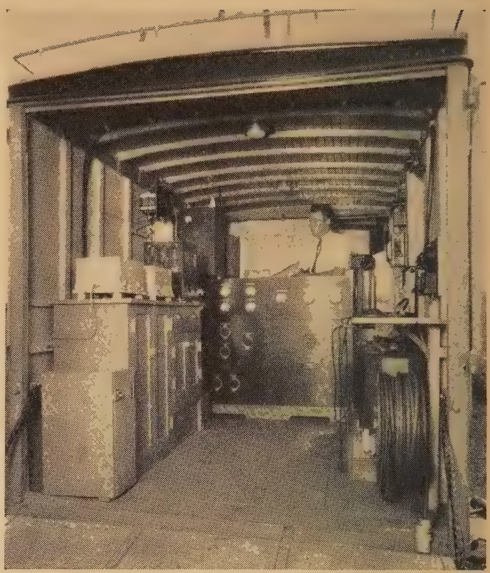


*Fig. 2—Within the body is complete radio equipment of the type used in both aircraft and ground terminals*

The battery has sufficient capacity to operate the aircraft equipment continuously for six hours. A power panel with main 220-volt switch for the alternating current supply, and the necessary relays and meters, is mounted over the battery. The field rheostat for the charging generator is also mounted on this panel.

The control units, consisting of the send-receive switch, tuning controls for the receivers, volume controls, and a clock, are mounted on an aluminum panel just above the operating table on the right-hand side of the truck. To avoid duplication of equipment the same control apparatus is used for both the 50-watt and the 400-watt equipments.

Bamboo is used for the antenna masts to secure maximum lightness. The mast on the truck, shown in the headpiece, is composed of six 7½-foot sections which rest on a block on top of the body, and is guyed with

hemp rope. The four lowest guys are fastened to the top of the truck and the other eight to stakes driven in the ground at convenient distances. The ground mast is similarly constructed and guyed but consists of only two 7½-foot sections.

The antenna may be either of the inverted "L" type or a fixed half-wave type with a single-wire transmission line connected to the 500-ohm point. Since each half-wave antenna is good for only one frequency, several antenna wires, cut to the correct lengths, are included in the equipment. Use has also been made of this portable station for the excitation of a number of special types of antennas, the efficiency of which for aircraft was under investigation.

This truck has also served as a ground station for communication with the Laboratories' planes in connection with demonstrations of our aircraft radio-telephone system at distant points where it is not possible to communicate with the Whippany ground station. On such occasions a loud speaker is mounted on the top of the truck (Figure 3) so that communication with aircraft may be heard by a group of people on the ground.

*Fig. 3—Truck-mounted portable radio station for aircraft survey work*

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